Ministry of Environment and Parks

SOURCE TESTING CODE FOR THE MEASUREMENT OF EMISSIONS OF TOTAL REDUCED SULPHUR COMPOUNDS FROM STATIONARY SOURCES

Waste Management Branch

and

Environmental Laboratory

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PREFACE

This draft code presents six standard test methods that will permit accurate and reproducible measurement of emissions of total reduced sulphur (TRS) compounds from stationary sources when such data are required under the Waste Management Act of the Province of British Columbia. At the present time these methods are considered to be reliable methods for the measurement of TRS which are comprised of four odoriferous sulphur compounds: Hydrogen Sulphide (H_2S), Methyl Mercaptan (MeSH), Dimethyl Sulphide (DMS), and Dimethyl Disulphide (DMDS).

From the date of its publication, this manual will be used as a draft code for a period of one year. During this period users of this code are requested to provide their suggestions to the Ministry. These suggestions will be given due consideration at the time of finalizing the draft code.

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METHOD 1:

Determination of Sampling Site and Traverse Points

METHOD 1: DETERMINATION OF SAMPLING SITE AND TRAVERSE POINTS

1.1 PRINCIPLE

A sampling site including the number and location of traverse points is selected to aid in obtaining velocity data. A single "reference" point is used as the site for gaseous sampling. Measurements of velocity at the reference point during sampling are used in combination with pre-sampling velocity data to provide the average stack gas velocity during sampling.

1.2 APPLICABILITY

This method is applicable to flowing gas streams in ducts, stacks, and flues. The method cannot be used when any of the following conditions apply:

i) Flow is cyclonic or swirling, i.e. the mean rotational angle for all sampling points exceeds 10°. Mean rotational angle is defined as the mean angle at all sampling points at which a null pressure reading is obtained in relation to a zero reference angle. The zero reference angle is defined as the stack cross-sectional plane.

ii) Stack cross-section is less than 0.071 m^2 (or 30.5 cm diameter).

iii) Measurement site is less than two stack diameters downstream or less than half a diameter upstream from a flow disturbance.

1.3 PROCEDURE

Selection of sampling site and minimum number of traverse points.

Preferably select a sampling site in a straight, vertical length of duct or stack at least eight duct or stack diameters downstream and two duct or stack diameters upstream from any flow disturbances such as a bend, expansion, contraction, junction, stack exit or visible flame, etc., in order to reduce the number of sampling points to the required minimum. A round section of the duct or stack shall be preferred over a rectangular section, all other variables being equal. For a rectangular duct, the equivalent diameter is defined in Equation 1.1.

Equation 1.1: $$D_e = \frac{2AB}{A+B}$$

where D_e = equivalent diameter, m

A,B = internal dimensions of rectangular duct, m

When the above sampling site criteria can be met, the minimum number of velocity traverse points required can be determined from Table 1.1. If the stack does not meet minimal 2 and 0.5 diameters from disturbances, the number of points should be 24 for a stack diameter >.61m and 20 for a stack diameter <.61m. For rectangular stacks use equivalent diameter and Table 1.1 to determine the minimum number of velocity measurement points. Then divide the cross section into as many equal rectangular areas as there are traverse points such that the ratio of length to width of the elemental area is between one and two.

TABLE 1.1

MINIMUM NUMBER OF VELOCITY MEASUREMENT POINTS FOR SAMPLING SITES LOCATED AT LEAST EIGHT DIAMETERS DOWNSTREAM AND TWO DIAMETERS UPSTREAM OF A FLOW DISTURBANCE

Duct Diameter m	Required Minimum Number of Sampling Points	
	Circular Duct	Rectangular Duct
>0.61	12	12
0.30–0.61	8	9

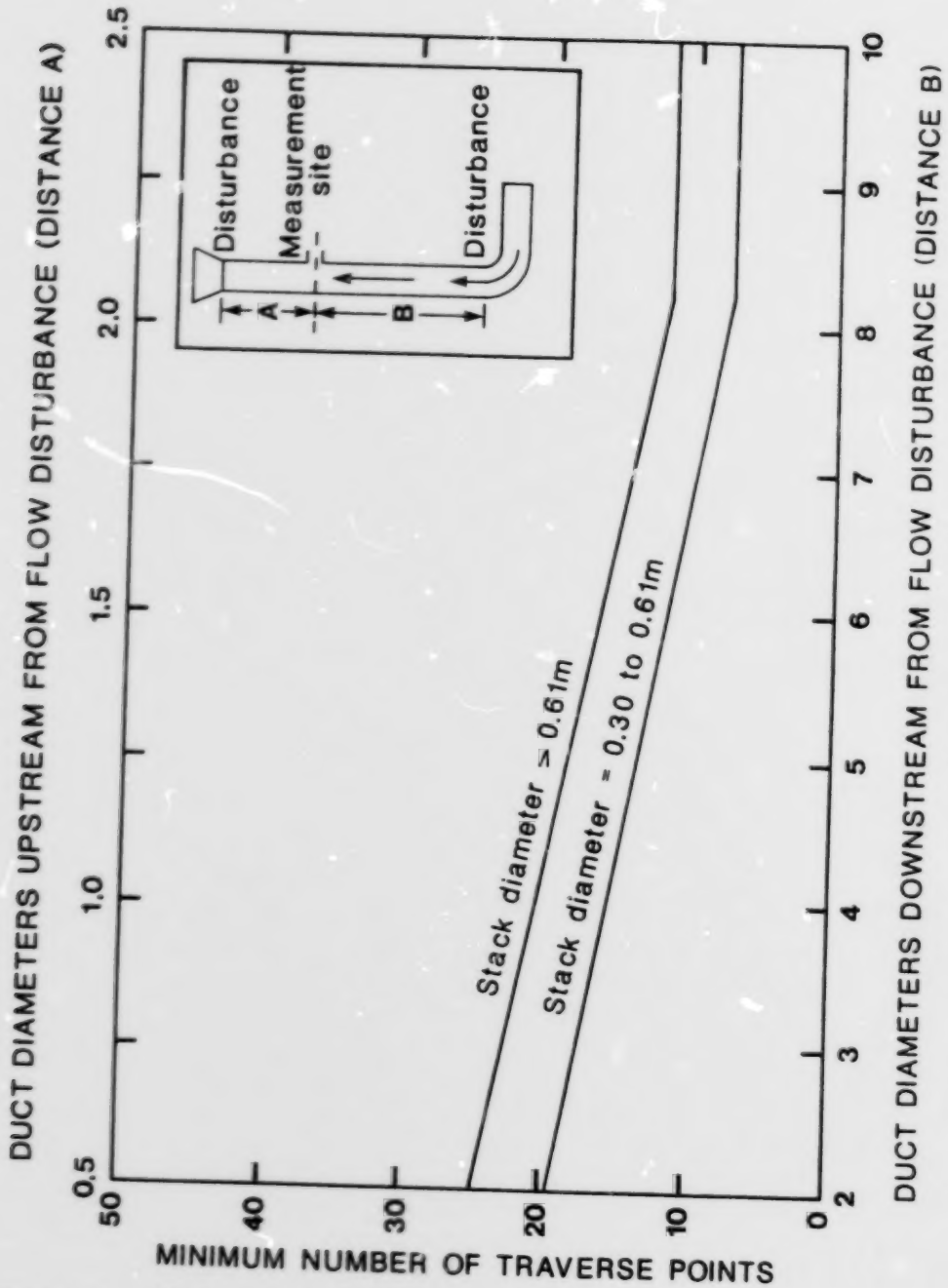

Figure 1.1 Minimum Number of Traverse Points for Velocity Traverses.

When the eight and two diameter criteria cannot be met, the minimum number of traverse points is determined from Figure 1 for velocity measurement. Before referring to the figure, determine the distance from the sampling site to the nearest upstream and downstream disturbance and divide each distance by the stack diameter to determine the distance in terms of the number of duct diameters. Then, determine from Figure 1 the minimum number of velocity traverse points that corresponds to (i) the number of duct diameters upstream and (ii) the number of duct diameters downstream. Select the higher of the two minimum numbers of traverse points, or a greater value so that for circular stacks the number is a multiple of 4 and for rectangular stacks the number is one of those shown in Table 1.2. For circular stacks traverses must be conducted in two perpendicular directions (see Figure 1.2) with one half the number of points on each traverse.

TABLE 1.2

CROSS SECTIONAL LAYOUT FOR RECTANGULAR STACKS

Number of Traverse Points	Matrix Layout
9	3x3
12	4x3
16	4x4
20	5x4
25	5x5
30	6x5
36	6x6
42	7x6
49	7x7

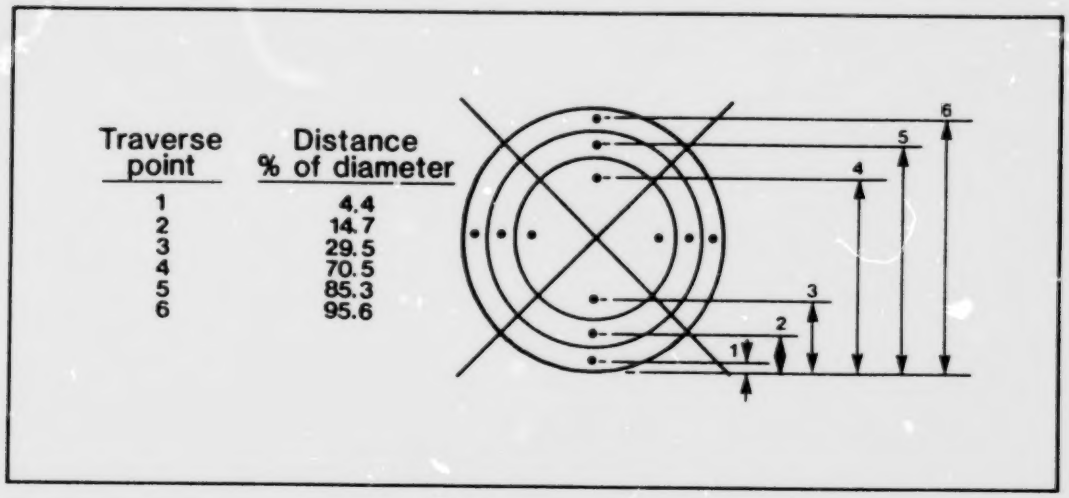

Figure 1.2 Location of Traverse Points on Circular Cross Section Divided into 12 Equal Areas

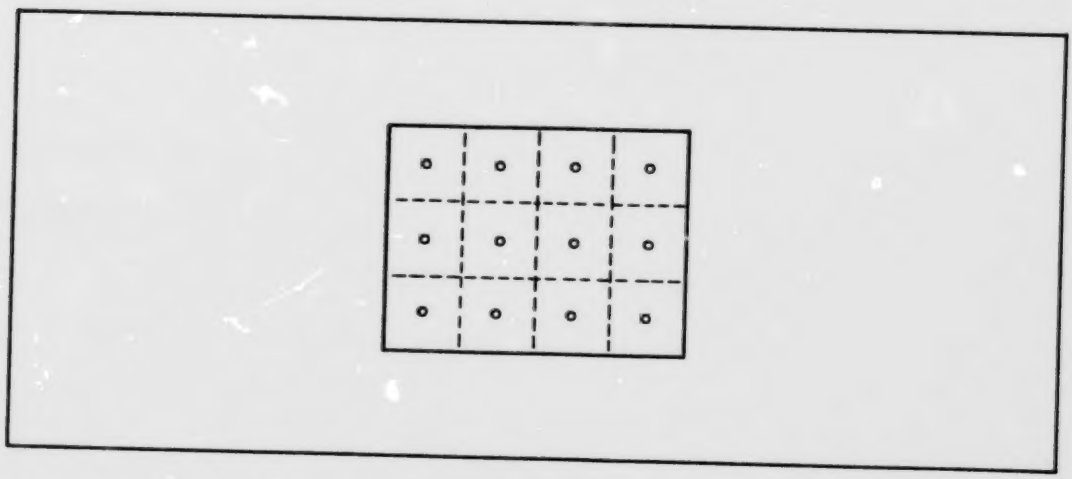

Figure 1.3 Location of Traverse Points on Rectangular Cross Section Divided into 12 Equal Areas

TABLE 1.3

LOCATION OF TRAVERSE POINTS IN CIRCULAR STACKS

Percent of Stack Diameter from Inside Wall to Traverse Point							
Traverse Point Number on a Diameter	Number of Traverse Points on a Diameter						
	2	4	6	8	10	12	14
1	14.6	6.7	4.4	3.3	2.5	2.1	1.8
2	85.4	25.0	14.7	10.5	8.2	6.7	5.7
3		75.0	29.5	19.4	14.6	11.8	9.9
4		93.3	70.5	32.3	22.6	17.7	14.6
5			85.3	67.7	34.2	25.0	20.1
6			95.6	80.6	65.8	35.5	26.9
7				89.5	77.4	64.5	36.6
8				96.7	85.4	75.0	63.4
9					91.8	82.3	73.1
10					97.5	88.2	79.9
11						93.3	85.4
12						97.9	90.1
13							94.3
14							98.2

Location of Traverse Points

For circular stacks the traverse points shall be located at the centroid of equal areas as indicated in Figure 1.3 and Table 1.3.

For rectangular stacks, the traverse points shall be located at the centroid of equal area rectangular zones as shown in Figure 1.4.

If a traverse point falls within 2.5 cm (stack diameter D >0.61 m) or 1.3 cm (stack diameter D <0.61 m) of the stack walls, relocate the traverse points to a distance of 2.5 cm (D >0.61 m) and 1.3 cm (D <0.61 m) away from the walls or equal to the nozzle diameter whichever is greater. These relocated traverse points shall be the adjusted traverse points.

Whenever two successive traverse points are combined to form a single adjusted traverse point, treat the adjusted point as two separate traverse points both in the sampling procedure and in recording the data.

Location of Sampling Points

For gaseous sampling, the sampling point shall be a single "reference" point. In circular stacks, the reference point shall be the centre of the stack. For rectangular stacks, the reference point shall be a point located near the centre on one of the traverses, which is also near the centre in the other dimension.

METHOD 2:

Determination of Stack Gas Velocity and Volumetric Flow Rate

METHOD 2: DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE

2.1 Principle

Stack gas velocity is determined from gas density and from measurement of velocity pressure with an S-type (Stauscheibe type) pitot tube. A standard pitot may be used where plugging of the tube openings is not a problem. A complete velocity profile of the emission is taken prior to gas sampling at each traverse point. Velocity readings at the reference point are made following each traverse point reading. A "flue factor" is calculated to relate velocity at the reference point to the overall stack velocity. Measurements of velocity at the reference point during sampling can be used to calculate an average stack gas velocity for the sampling period. Volumetric flow rate is determined from measurements of the following stack parameters: gas velocity, temperature, pressure, dry gas composition, moisture and diameter.

2.2 Applicability

The method is used for the measurement of the average velocity of a gas stream and quantifying gas flow and is applicable in those situations where stack gas velocity varies with respect to time. Method 2 is not applicable if cyclonic flows exist (see Method 1) or if there are fluctuating velocity pressure (Δp) readings where the fluctuation exceeds ±20% of the average reading.

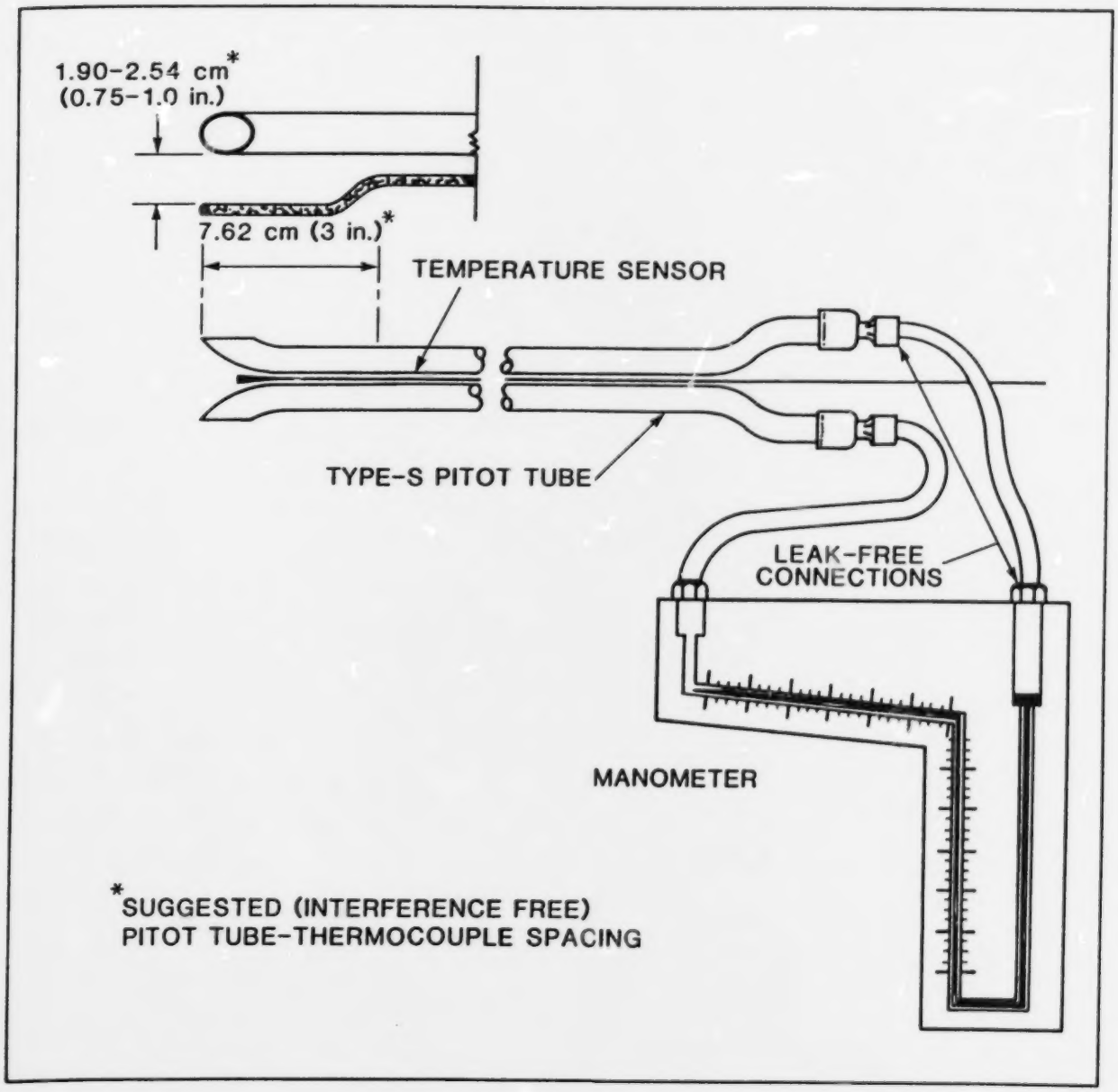

Figure 2.1 S-Type Pitot Tube and Manometer Assembly

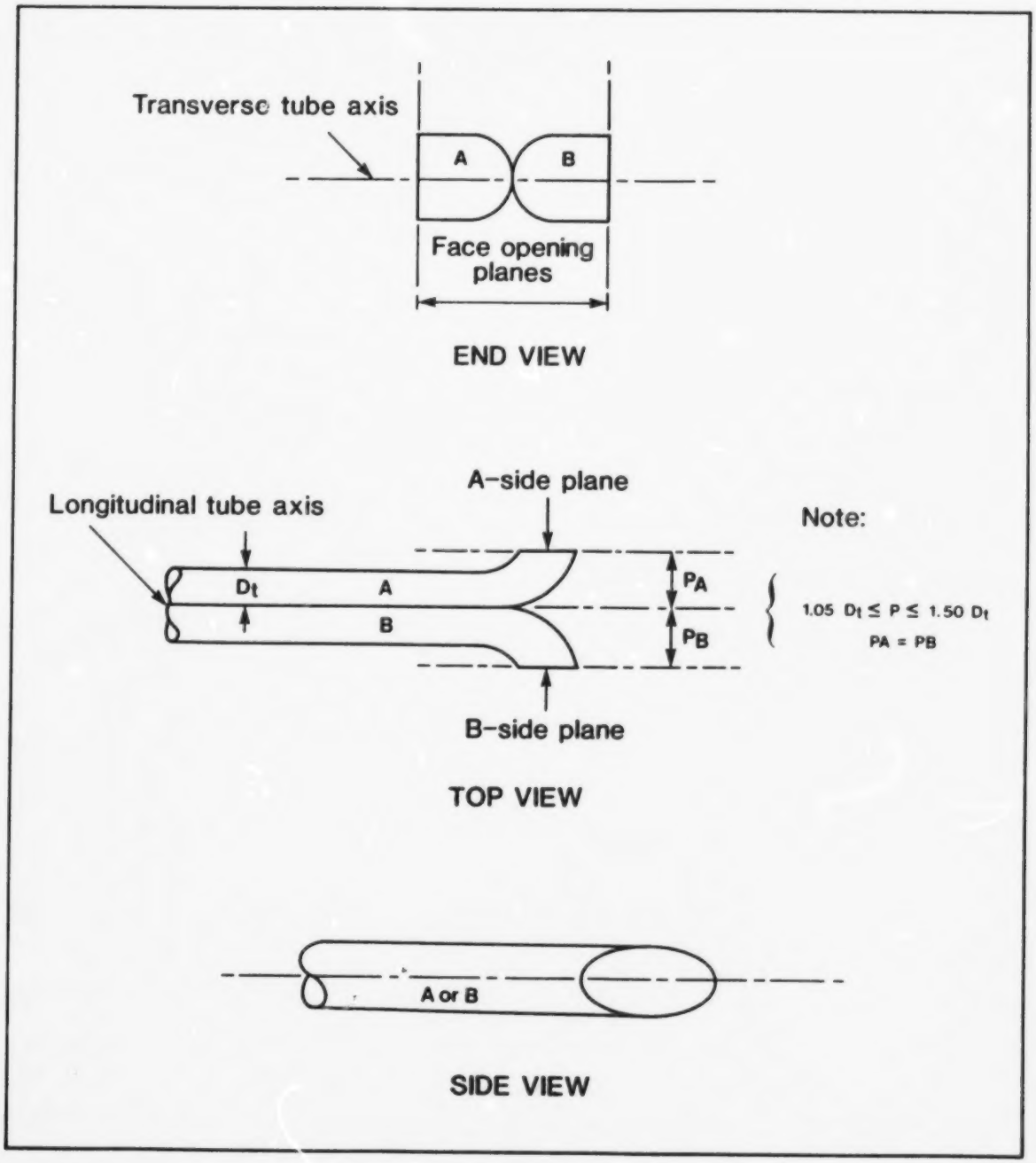

Figure 2.2 Design of an S-Type Pitot Tube

2.3 Apparatus

S-Type Pitot Tube and Thermocouple

A stainless steel, or "Inconel" calibrated S-type pitot tube with an attached calibrated, sheathed thermocouple shall be used to measure the gas velocity head and temperature at each traverse point in the stack. Figure 2.1 illustrates the S-type pitot tube. A properly constructed S-type pitot tube shall meet the design specifications of Figure 2.2. An inclined manometer or equivalent device used to measure velocity head shall have an accuracy of 0.001 kPa. The thermocouple shall have an accuracy of 1.5 percent of the minimum absolute stack temperature. The S-type pitot tube shall be calibrated in accordance with the procedure given in the Appendix.

Barometer

A barometer shall be used to measure the atmospheric pressure to within 0.35 kPa at the sampling site.

2.4 Procedure

Set up the apparatus as shown in Figure 2.1. Make sure all connections are leak free. Measure the stack dimensions and determine the velocity traverse points according to Method 1. Measure the velocity and temperature concurrently at the traverse point and the reference point and record the measurements on the data sheet illustrated in Table 2.1.

Determine the stack gas static pressure by disconnecting one leg of the pitot tube from the manometer and then rotating the assembly until the openings in the pitot tube are perpendicular to the gas flow. This reading may be positive or negative depending on the conditions in the stack. If a magnehelic is used to measure static pressure it will

be necessary to switch over the pitot connection in case of negative static pressure. This will allow a negative static pressure to be indicated on a positive scale. Record the atmospheric pressure, P_b.

Determine the stack gas molecular weight according to Method 3.

TABLE 2.1

VELOCITY TRAVERSE DATA SHEET

Plant _____ Stack Dia. (m) _____

Location _____ Barometric press. (kPa) _____

Test _____ Static press. in stack (kPa) _____

Date _____ S-type pitot coefficient _____

Time started _____ Test conducted by _____

Time completed _____

Traverse Point	Stack Gas Velocity Pressure Δp	Stack Gas Temperature T_s	Velocity Pressure Reference $(\Delta p)_R$	Temperature Reference $(T_s)_R$	Stack Gas Velocity U_s or U_R

2.5 CALCULATIONS

Determine the stack gas velocity at each traverse point including the paired reference point using Equation 2.1.

$$U_s \text{ or } U_R = K_p \cdot C_p \left(\frac{T_s \cdot \Delta p}{P_s \cdot M_s} \right)^{1/2} \qquad \text{Eq. 2.1}$$

Where

U_s = stack gas velocity at each traverse point, m/s

U_R = stack gas velocity at reference point, m/s

K_p = constant, $128.53 \frac{m}{s} \left(\frac{kg}{(K)(kmol)} \right)^{1/2}$

C_p = S-type pitot tube coefficient, dimensionless

T_s = absolute stack gas temperature, K

Δp = stack gas velocity pressure, kPa

P_s = absolute stack gas pressure, see Equation 2.2, kPa

M_s = molecular weight of stack gas on wet basis, $\frac{kg}{kmol}$
(Refer to Method 3)

Determine absolute stack gas pressure using Equation 2.2.

$$P_s = P_b + P_{stat} \qquad \text{Eq. 2.2}$$

Where

P_s = absolute stack gas pressure, kPa

P_b = barometric pressure at the sampling station, kPa

P_{stat} = stack gas static pressure, kPa

Determine the flue factor for the emission using Equation 2.3

$$F = [\Sigma(U_S/U_R)]N \qquad \text{Eq. 2.3}$$

where F = flue factor

U_S = stack gas velocity at each traverse point, m/s

U_R = stack gas velocity at the 'reference point', m/s

N – number of paired simultaneous measurements of U_S and U_R

The factor F may be applied to velocity readings taken at the reference point during subsequent gas sampling. The average stack gas velocity can be determined from reference point measurements of velocity using Equation 2.4.

$$(U_S)_{avg} = F \times (U_R)_{avg} \qquad \text{Eq. 2.4}$$

where $(U_S)_{avg}$ = average stack gas velocity, m/s

F = Flue Factor

$(U_R)_{avg}$ = average stack gas velocity at the reference point, m/s

Determine the volumetric gas flow rate using Equation 2.5.

$$Q_S = (U_S)_{avg} \cdot A_S \cdot (1-B_{wo}) \frac{(T_{ref}) \cdot (P_S)}{(T_S)_{avg} \cdot (P_{ref})} \qquad \text{Eq. 2.5}$$

Where

Q_S = volumetric gas flow rate on dry basis at reference conditions, m^3/s

$(U_S)_{avg}$ = average stack gas velocity, m/s

A_S = cross-sectional area of stack, m^2

B_{wo} = fraction by volume of water vapour in gas
(Refer to Method 4, Equation 4.3)

T_{ref} = absolute temperature at reference condition, 293 K

$(T_S)_{avg}$ = average absolute stack gas temperature, K

P_S = absolute stack gas pressure, kPa

P_{ref} = absolute pressure at reference conditions, 101.3 kPa

Where

M_s = molecular weight of gas on wet basis, $\frac{kg}{kmol}$

B_{wo} = decimal fraction by volume of water vapour in stack gases, dimensionless

M_d = molecular weight of stack gas on dry basis, $\frac{kg}{kmol}$

METHOD 3:

Determination of Gas Composition and Molecular Weight

METHOD 3: DETERMINATION OF GAS COMPOSITION AND MOLECULAR WEIGHT

3.1 PRINCIPLE

The molecular weight of the stack gas varies with the process under consideration and is calculated from an analysis of the gas composition. After isolation of the sample, analysis of the stack gas composition for CO_2 and O_2 may be achieved by selective absorption using liquid reagents (Fyrite and Orsat Analyzers) or by gas chromatography.

3.2 APPLICABILITY

The method is applicable to gas streams where all significant concentrations of the gases present can be analyzed.

3.3 APPARATUS

While grab sampling is acceptable in many cases, integrated sampling should be used for gas streams with varying composition.

(a) Grab Sampling

i) Sampling Probe

A stainless steel or Pyrex probe equipped with a filter to remove heavy particulate matter.

ii) Sample Extraction Device

A one way squeeze bulb or a leak-free diaphragm-type pump.

iii) Moisture Removing Device

A device to remove water from the gas stream without removing the gaseous components required when analysis is to be performed by gas chromatography.

iv) Gas Analyzer

Orsat or Fyrite analyzer or alternate device such as gas chromatograph provided that gas component percentage is measurable to at least 0.2% and is determined on a dry basis.

(b) Integrated Sampling (Figure 3.1)

i) Sampling Probe - as above

ii) Sample Extraction Device

A leak free diaphragm-type pump or equivalent; a device to dampen diaphragm pulsation effect.

iii) Moisture Removing Device - as above

iv) Valve

A needle valve to adjust sample gas flow rate.

v) Flow Rate Meter

Rotameter or equivalent device to measure flow within ±2%.

vi) Flexible Bag

Leak free, inert, Tedlar bag, suggested capacity 30 litres.

vii) Gas Analyzer - as above

3.4 PROCEDURE

(a) Grab Sampling

Assemble the analyzer, calibrate and ensure that all connections are leak free. Position the probe at the centre of the stack or at a point no closer than 1.0 m to the walls of the stack. Purge the sampling system and

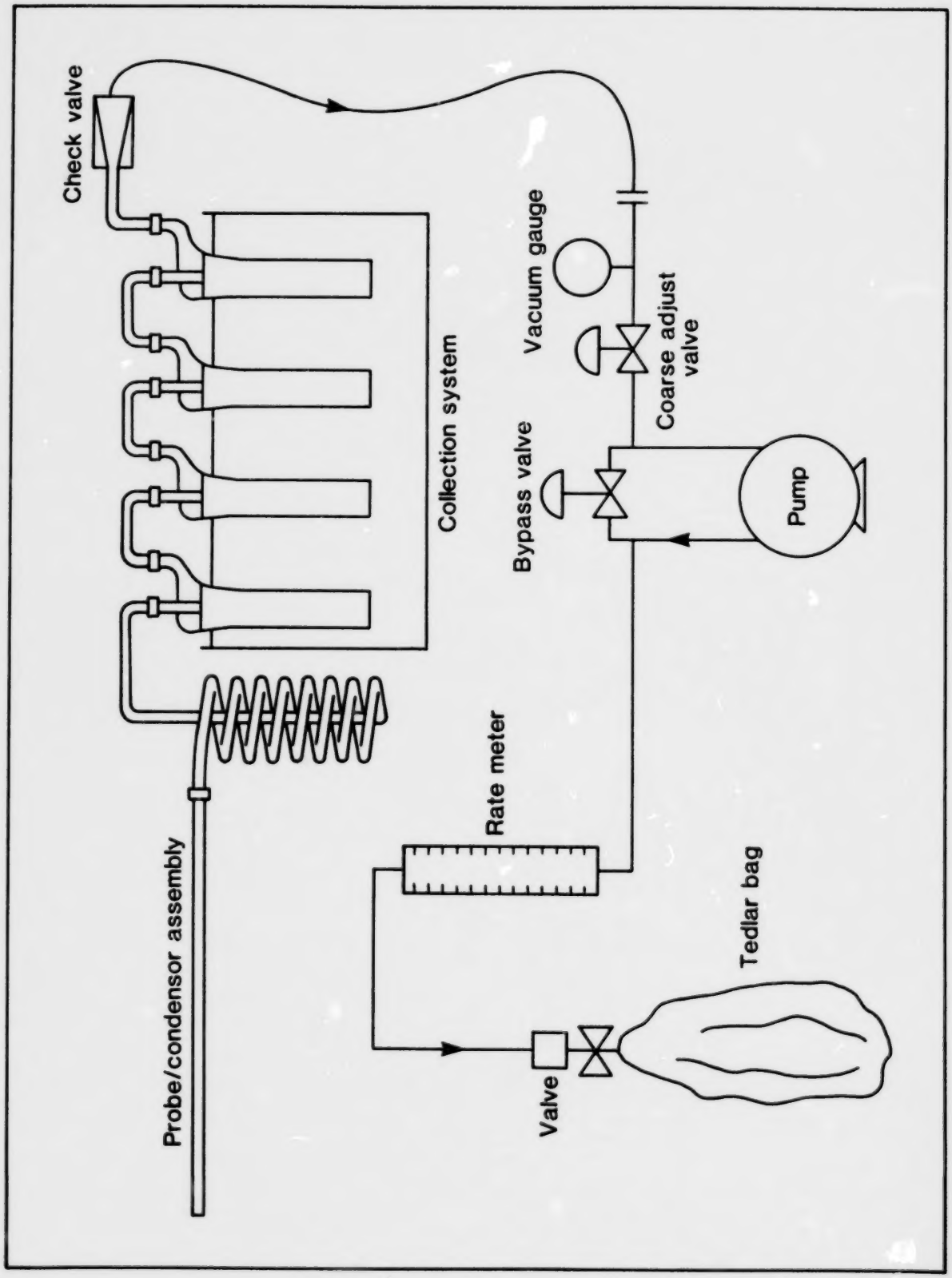

Figure 3.1 Train for Integrated Gas Sampling

then draw a sample into the analyzer and analyze for percentage of CO_2 and O_2. Samples must be taken at the start, midpoint and conclusion of the measurement period. Record the measurements on the data sheet illustrated in Table 3.1.

(b) Integrated Sampling

Assemble the integrated sampling train as shown in Figure 3.2. Leak test the train. Evacuate the Tedlar bag and connect it to the sampling train. Position the sampling probe either at the centre of the stack or at a point at least 1.0 m from the stack wall. Sample at a constant rate and analyze for percentage of CO_2 and O_2. Record the measurements on the data sheet illustrated in Table 3.1.

3.5 CALCULATIONS

Calculate the stack gas molecular weight on a dry basis using Equation 3.1.

$$M_d = 0.44\ (\%\ CO_2) + 0.32\ (\%\ O_2) + 0.28\ [100-(\%CO_2 + \%\ O_2)] \qquad \text{Eq. 3.1}$$

Where

M_d = molecular weight of stack gas on dry basis, $\frac{kg}{kmol}$

$\%\ CO_2$ = percent carbon dioxide by volume on dry basis

$\%\ O_2$ = percent oxygen by volume on dry basis

Determine molecular weight of the stackgas on a wet basis using Equation 3.2.

$$M_s = M_d\ (1-B_{wo}) + 18\ B_{wo} \qquad \text{Eq. 3.2}$$

TABLE 3.1

GAS COMPOSITION DATA SHEET

Plant _____

Location _____

Test _____

Date _____

Operators _____

Time	Test number	$\%CO_2$	$\%O_2$

Where

M_s = molecular weight of gas on wet basis, $\frac{kg}{kmol}$

B_{wo} = decimal fraction by volume of water vapour in stack gases, dimensionless

M_d = molecular weight of stack gas on dry basis, $\frac{kg}{kmol}$

METHOD 4:

Determination of Moisture Content of Stack Gas

METHOD 4: DETERMINATION OF MOISTURE CONTENT OF STACK GAS

4.1 PRINCIPLE

A gas sample is extracted from the stack either at a constant rate or isokinetically. Moisture is removed from the sample stream by passing it through a condenser system immersed in an ice bath, and moisture content determined gravimetrically.

If saturated or water droplet laden gas streams are suspected a second determination of moisture content shall be made using either (i) a psychrometric chart, Figure 4.1 or (ii) saturation vapour pressure tables The lower of the two values obtained shall be considered as the correct moisture content of the stack gas.

4.2 APPLICABILITY

The reference method is applicable for accurate determinations of moisture content in exhaust gases from stationary sources. The method is not applicable if an appreciable amount of condensate other than water is present. Methods such as wet and dry bulb techniques may be used for approximate estimates of moisture contents to aid in setting a proportional sampling rate.

4.3 APPARATUS

A standard particulate sampling train, shown in Figure 4.2, and a portable field balance shall be used to determine moisture content of the stack gas.

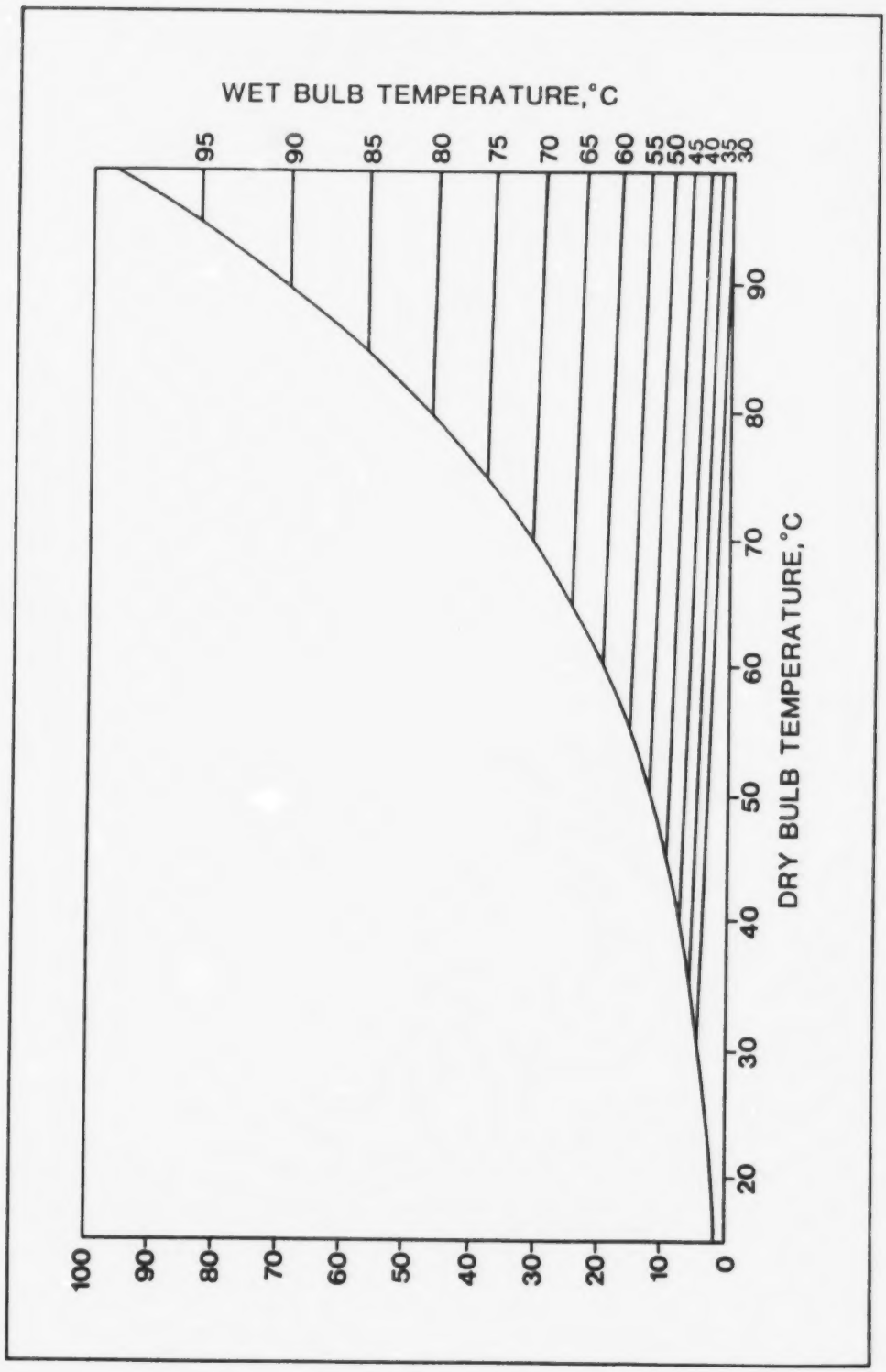

Figure 4.1

High Temperature Psychrometric Chart for Air-Water Vapour Mixtures at 101.3 kPa

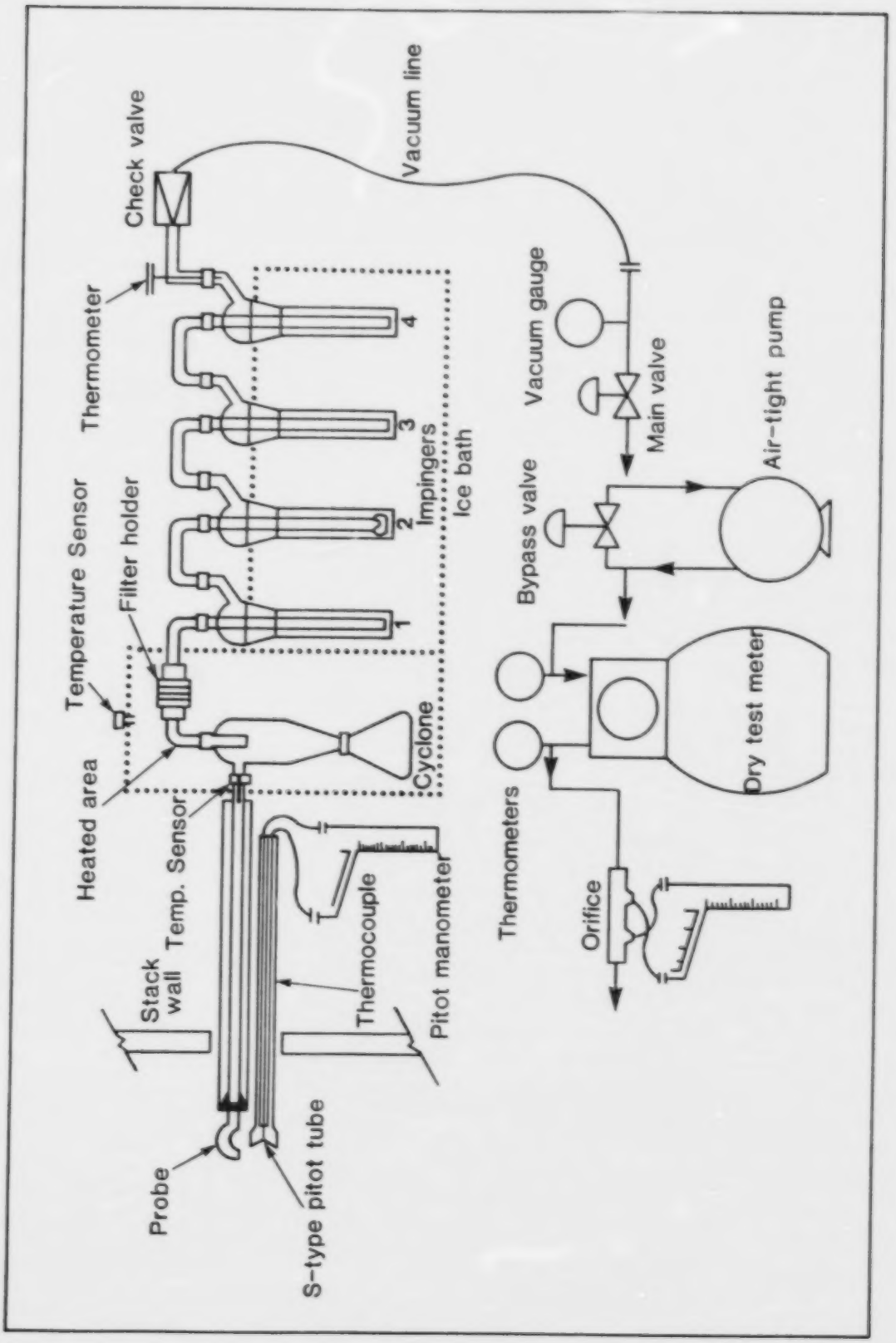

Figure 4.2 Moisture/Particulate Sampling Train

4.4 PROCEDURE

Measure the atmospheric pressure at the sampling site using a barometer. Place measured amounts (approximately 100 mls) of water in the first two impingers. Liquid droplets carried over from the first two impingers are removed in the third unit which serves as a knock-out separator. The last traces of moisture are removed in the fourth impinger containing silica gel or other suitable desiccant.

Weigh the impingers and their contents to the nearest 0.1 g and record the weights. Assemble the sampling train as shown in Figure 4.2 and Leak Test it. Select a sampling position near the centre of the stack or at a minimum distance of one metre away from the walls. Sample isokinetically or at a constant rate of 0.02 m^3/min until a measurable amount of water vapour has been condensed in order to make a reliable estimate of the moisture content. Determine the weight increase in the impingers to the nearest 0.1 gm. As the test progresses, record the data on the data sheet illustrated in Table 4.1.

4.5 CALCULATIONS

Use Equation 4.1 to calculate the reference volume of dry gas sampled.

$$(V_m)_{ref} = \nu V_m \left(\frac{T_{ref}}{T_m}\right)\left(\frac{P_b + \Delta H}{P_{ref}}\right) \qquad \text{Eq. 4.1}$$

Where

$(V_m)_{ref}$ = volume of gas through dry gas meter at reference conditions (293 K, 101.3 kPa), m^3

ν = dry gas meter correction factor, dimensionless

TABLE 4.1

MOISTURE ANALYSIS DATA SHEET

Plant _____

Location _____

Date _____

Barometric Pressure kPa _____

Dry Gas Meter Correction Factor, Dimensionless _____

Total Weight Increase in Impingers, g _____

Time min	Meter volume reading m^3	Meter temperature °C		Orifice pressure drop ΔH kPa
		inlet	outlet	

V_m = volume of gas measured by dry gas meter at meter conditions, m^3
ΔH = average pressure drop across orifice, kPa
T_m = average meter temperature, K
P_b = barometric pressure, kPa
P_{ref} = absolute pressure at reference conditions, 101.3 kPa
T_{ref} = absolute temperature at reference condition, 293 K

Use Equation 4.2 to calculate the volume of water vapour collected.

$$(V_w)_{ref} = \frac{\Delta W \cdot R \cdot T_{ref}}{P_{ref} \cdot M_{H_2O} \cdot 10^6} \qquad \text{Eq. 4.2}$$

Where

$(V_w)_{ref}$ = volume of water vapour collected at reference conditions, m^3
ΔW = the total increase in the weight of impingers, g.

R = ideal gas constant, 8.31 $\frac{\text{kPa m}^3}{\text{kmol K}}$

T_{ref} = absolute temperature at reference conditions, 293 K
P_{ref} = absolute pressure at reference conditions, 101.3 kPa
M_{H_2O} = molecular weight of water, 18 kg/kmol

The moisture content of the gas is then determined by using Equation 4.3.

$$B_{wo} = \frac{(V_w)_{ref}}{(V_w)_{ref} + (V_m)_{ref}} \qquad \text{Eq. 4.3}$$

Where

B_{wo} = fraction by volume of water vapour in the gas stream, dimensionless

$(V_w)_{ref}$ = volume of water vapour in the gas sample at reference conditions, m^3

$(V_m)_{ref}$ = volume of gas sample through the dry gas meter at reference conditions, m^3

METHOD 5:

Determination of Total Reduced Sulphur Compounds in Emissions from Stationary Sources using Grab Sampling

METHOD 5: DETERMINATION OF TOTAL REDUCED SULPHUR COMPOUNDS IN EMISSIONS FROM STATIONARY SOURCES USING GRAB SAMPLING

5.1 PRINCIPLE

A gas sample is extracted from the stack gas, passed through an impinger containing concentrated phosphoric acid to remove water vapour and then collected in a Teflon bottle. An aliquot of the sample contained in the Teflon bottle is analyzed for hydrogen sulphide (H_2S), methyl mercaptan (MeSH), dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) by gas chromatograph (GC) separation and flame photometric detection (FPD). These four compounds are known collectively as total reduced sulphur (TRS).

5.2 APPLICABILITY

This method is applicable for determining the concentration of total reduced sulphur compounds from stationary emission sources such as recovery furnaces, lime kilns and smelt dissolving tanks at Kraft Pulp Mills, etc. When a concurrent volumetric flow rate is known the emission rate may also be determined.

5.3 SENSITIVITY

The detection limit may vary according to the gas chromatograph specifications, separation column and the operating parameters. Under the analytical conditions described in this code and using a 1 ml sample loop, concentrations of TRS measured as H_2S to 1.41 mg/m^3 (1 ppm) can be detected.

5.4 INTERFERENCES

The presence of SO_2 and COS may interfere if the concentrations are sufficiently high to degrade the resolution of instrument response to the individual TRS compounds.

Variations in background composition (i.e. the $N_2/O_2/CO_2/CO$/water vapor composition) between samples and standards may result in interference by modifying peak shapes and/or affecting detector response.

Any chemical alteration or degradation of the sample between the time of sampling and analysis will result in a negative interference.

5.5 APPARATUS

Sampling Train

Probe Assembly

The probe assembly is constructed of stainless steel and attaches to the stack port as shown in Figure 5.1. The complete assembly incorporates a cover for the port opening as well as a holder for both the midget impinger and bottle assembly. The probe itself shall be constructed of 6.35 mm (1/4") inside diameter stainless steel with a 6.35 mm (1/4") outside diameter teflon liner. The probe exit shall have a Swagelock fitting.

Filter

A wad of quartz wool, at the inlet end of the probe, may be used to filter out particulate matter.

Impinger

A standard 25 mL capacity midget impinger containing 10 ml 85% v/v H_3PO_4 is used to remove water vapour.

Bottle Assembly

A 500 mL teflon bottle fitted with an airtight cap incorporating 6.35 mm (1/4") O.D. teflon tubing and a Swagelock fitting is attached to a 3 way valve (see Figure 5.1). Bottle assemblies are leak tested by pressurizing to 25 cm H_2O gauge and observing the rate at which the pressure drops. The rate must be less than 1 cm H_2O over a 20 minute period.

Tubing

All tubing used in the sampling assembly shall be 6.35 mm (1/4") O.D. teflon tubing. The tubing connecting the probe exit and the impinger inlet shall be as short as possible and if required it should be heated (using either heating tape or a hot air blower) to prevent condensation of moisture.

5.6 Procedure

Preliminary

Select a suitable sampling location. The sampling point must be either at the centre of the stack or at least 50 cm from the nearest stack wall. Ensure that all bottle assemblies to be used in the sampling program have been leak tested.

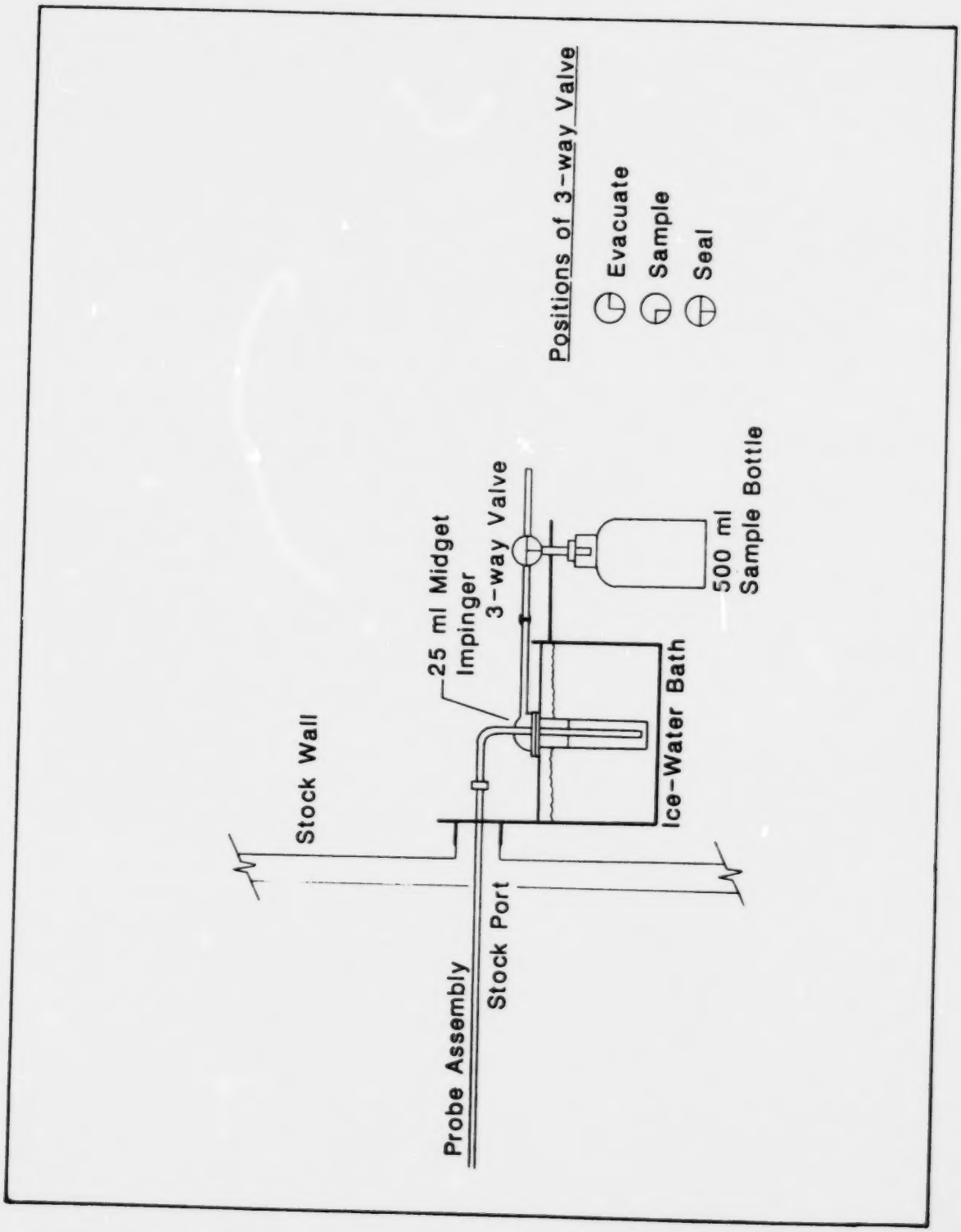

Figure 5.1 Sampling Train

Sampling Procedure

Set up the sampling train as shown in Figure 5.1.

With the 3 way valve set for the evacuate position (see Figure 5.1) squeeze the teflon bottle to expel as much contained air as possible. Turn the 3 way valve to the sample position and release the pressure on the bottle and allow the teflon bottle to fill completely. Repeat the evacuate/sample procedure at least 10 times to ensure that the sample taken contains no residual dilution air. Turn the valve to the seal position. Allow the bottle to stand for 10 minutes to condition the surfaces.

Turn the valve to the evacuate position and squeeze the bottle to expel as much gas as possible. Turn the valve to the sample position and release the pressure on the Teflon bottle and allow it to fill completely. Repeat the evacuate/sample cycle at least 10 times.

At the conclusion of sampling turn the valve to the seal position and disconnect it from the impinger. The bottle and valve are then transported to the gas chromatograph for analysis.

Complete a field sampling data sheet as shown in Table 5.1.

Valid Stack Survey

A valid stack survey will require collecting at least 8 samples at intervals of not less than 15 minutes over a 2-hour time period. The analysis of each individual sample must be completed within 1 hour of taking the sample.

TABLE 5.1

Field Sampling Data Sheet

COMPANY _____

PLANT LOCATION _____

SOURCE TESTED _____

DATE _____

TIME OF SAMPLING _____

BAROMETRIC PRESSURE _____kPa $B_{x}o$ _____

AVERAGE STACK TEMP. _____°C

PULP PRODUCTION _____

AVERAGE STACK GAS VELOCITY _____m/s

DIMENSION(S) OF STACK _____

ABSOLUTE STACK PRESSURE _____ kPa

NAME OF SAMPLING CREW LEADER _____

_____

ATTACH TO THIS SHEET:

(a) Sheet giving sampling location details along with the number and location of points for average velocity determination

(b) Table 2.1, Velocity Traverse Data Sheet

(c) Table 3.1, Gas Composition Data Sheet

(d) Table 4.1, Moisture Analysis Data Sheet

5.7 ANALYSIS

Analytical Equipment

Gas Chromatograph

A gas chromatograph having a linearly temperature programmable oven, flame photometric detector equipped with a narrow band pass filter of 393 nm, potentiometric strip chart recorder and automatic integrator shall be used to analyze the gaseous samples (see Figure 5.2). The Gas Chromatograph shall also incorporate the following features:

Chromatographic Column

The separation column shall be a teflon (FEP) tube 1.4 metres long, with a 3.1 mm O.D. and packed with Carbopak B-HT 100. Before initial use the column should be conditioned for at least 18 hours at 120°C with 10 ml/min flow of helium gas. This column will resolve SO_2 and the four major reduced sulfur compounds: H_2S, MeSH, DMS and DMDS.

Gas Controls

Carrier and fuel gases used with the gas chromatograph shall be reproducibly flow-adjustable by either pressure or flow regulation and monitored by rotameters or other flow-measuring devices.

Sampling Valve

A teflon 6 port gas samping valve equipped with a 1.0 mL sample loop shall be used.

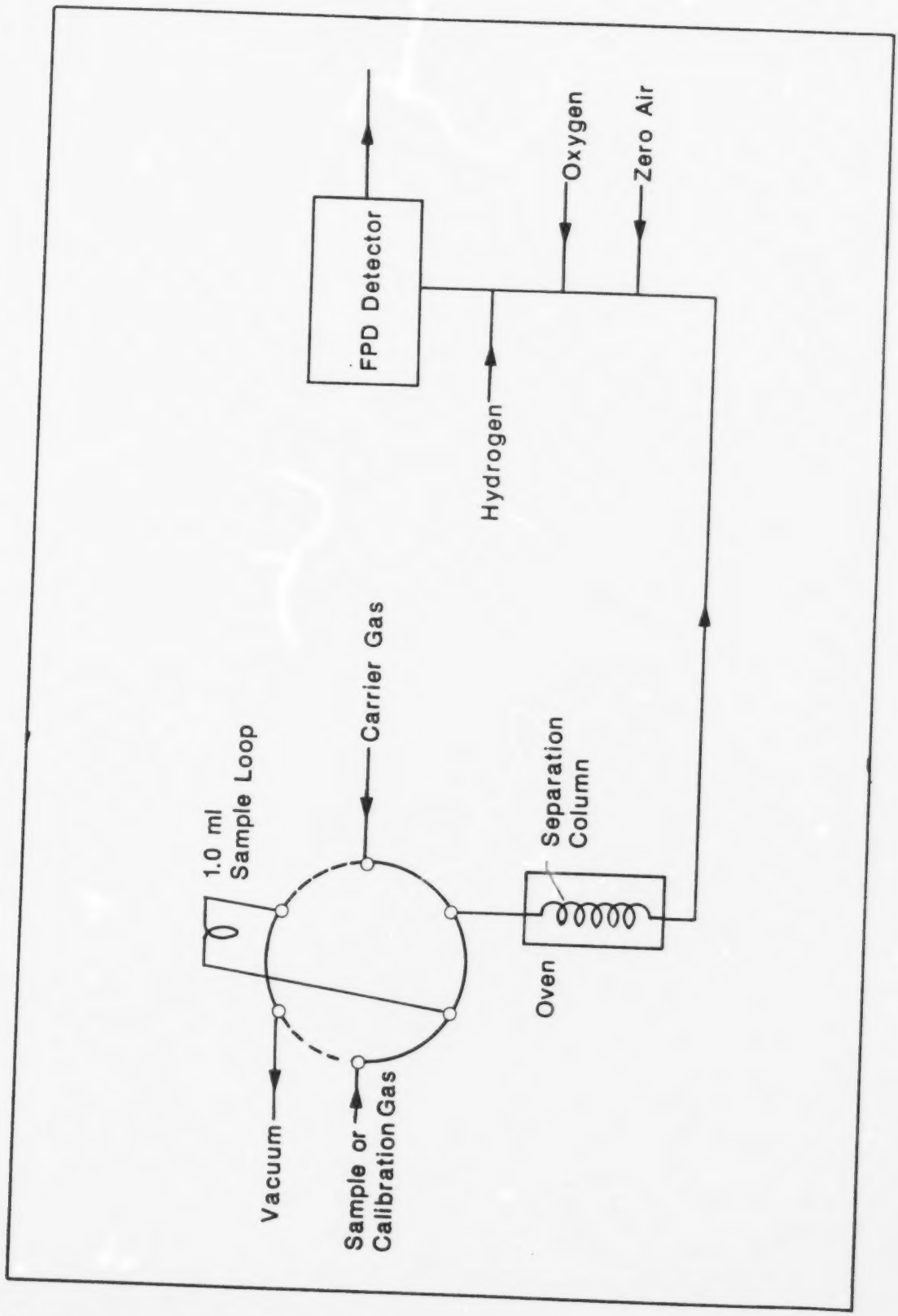

Figure 5.2 Analytical Train

Dilution System

Calibration standards shall be supplied by the dilution of certified cylinder gases containing TRS in nitrogen. The certified cylinder gases must be provided in aluminum cylinders and the use of blends of more than one TRS compound in the same cylinder is optional. Dilution is achieved using zero air and mass flow control (see Figure 5.3). All tubing used in the dilution system must be teflon. If the concentration of the certified cylinder gas is C, the flow of the cylinder gas F_i and the combined flow F_T, then the concentration of the TRS standard is $C_{STD} = C(F_i/F_T)$. Note that the ratio $\Sigma F_i : F_T$ should generally not exceed 1:10. All standards must have certified analyses traceable to primary permeation standards which have been calibrated gravimetrically.

Analytical Procedure

Operating Parameters

Operating parameters (temperatures and flow rates) for the G.C. follow:

Temperatures

Detector:	150°C
Oven:	maintain at 50°C for 3 min., then raise to 115°C at a rate of 30°C/min and hold at 115°C for 10 min.

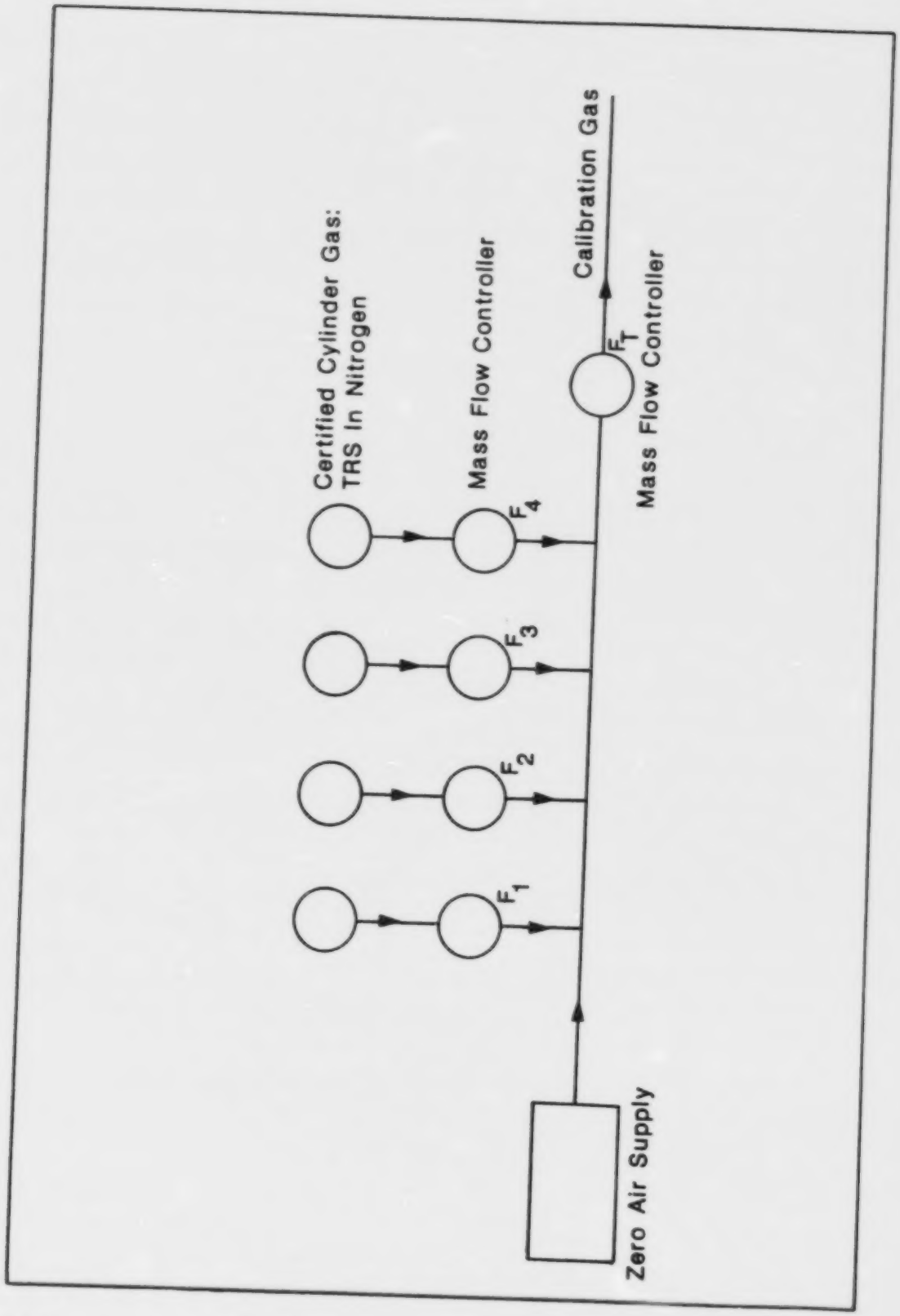

Figure 5.3 Dilution System

Flow Rates

Carrier Gas: He:		50 mL/min
Combustion Gases;	H_2:	200 mL/min
	Zero Air:	50 mL/min
	O_2:	50 mL/min

Note that the above flow rates for the carrier and combustion gases are approximate only and the exact flows will depend upon the equipment used. To optimize FPD response inject a series of H_2S standards (e.g. 5 ppm) and, maintaining all other flows constant, adjust the oxygen flow so as to produce the maximum detector response. All flow rates must be maintained constant during all subsequent analyses and calibration runs.

Calibration

Optimize FPD response and determine that stable operating conditions have been achieved. Record all instrument settings (Table 5.2); i.e., temperatures, flow rates, etc., including gain settings. Connect the dilution system to the gas inlet of the sampling valve and set the sampling rate to 50 mL/min. Adjust the mass flow controllers to deliver the required combined TRS standard and then activate the analytical sequence. The calibration standards will generally accommodate analytical ranges of either 0-10 or 0-100 ppm. Four standards (e.g., 1,2,5 and 10 ppm) must be used to define the calibration curve for each range. Use log-log graph paper to construct the calibraton curves by plotting TRS concentration versus detector response (i.e., peak area). Note that the gain settings used during calibration must remain the same during subsequent sample analysis.

TABLE 5.2

TRS ANALYSIS DATA SHEET

COMPANY _____

PLANT LOCATION _____

SOURCE TESTED _____

DATE _____

ANALYST _____

LABORATORY TEMPERATURE _____ °C ATMOSPHERIC PRESSURE _____ kPa

G.C. OPERATING CONDITIONS

TEMPERATURES: Injection Port _____ °C Detector _____ °C

Oven Program _____

VOLUME OF GAS INJECTED _____ ml

Gas	O_2	H_2	Air	He
Pressure psig				
Flow rate ml/min				

ANALYTICAL RESULTS

Injection No.	Time	Concentrations (ppm)				Concentration of TRS-ppm (as H_2S)	Remarks
		H_2S	CH_3SH	$(CH_3)_2S$	$(CH_3)_2S_2$		
					AVERAGE TRS CONC.		

Sample Analysis

Disconnect the vacuum line to the sampling valve and connect the sample bottle assembly to the gas inlet of the sampling valve. Open the 3 way valve and then squeeze the sample bottle so that the sample loop is completely filled with sample. Return the 3 way valve to the seal position. Allow 30 seconds for the pressure in the sample loop to stabilize. Activate the analytical sequence by manually turning the sampling valve to the inject position and simultaneously starting the integrator. Record the peak areas and reference them against the calibration curves to obtain the concentration of the individual TRS compounds (Table 5.2).

At the conclusion of the analytical run verify the stability of the calibration by running a single combined TRS standard. The expected and observed results must agree to within ±10%.

5.8 CALCULATIONS

TRS Concentration

Determine the average concentration of TRS, during the sampling period, using Equation 5.1.

$$C_{TRS} = \frac{1.41}{N} \sum (C_{H_2S} + C_{MeSH} + C_{DMS} + 2C_{DMDS}) \quad \text{Eq. 5.1}$$

where:

C_{TRS} = average concentration of TRS (as H_2S) at reference conditions mg/m^3

N = number of samples analyzed

C_{H_2S} = H_2S concentration in ppm

C_{MeSH} = MeSH concentration in ppm

C_{DMS} = DMS concentration in ppm

C_{DMDS} = DMDS concentration in ppm

Volumetric Gas Flow Rate

Determine the volumetric gas flow rate, during the sampling period, using Equation 5.2

$$Q_s = (U_s)avg \cdot A_s \cdot (1-B_{wo}) \frac{(T_{ref}) \cdot (P_s)}{(T_s)avg \cdot (P_{ref})} \qquad \text{Eq. 5.2}$$

where:

Q_s = volumetric gas flow rate on dry basis at reference conditions, m^3/s

$(U_s)_{avg}$ = average stack gas velocity, m/s

$(A_s)avg$ = cross-sectional area of stack, m^2

B_{wo} = fraction by volume of water vapour in gas

T_{ref} = absolute temperature at reference condition, 293 K

$(T_s)avg$ = average absolute stack gas temperature, K

P_s = absolute stack gas pressure, kPa

P_{ref} = absolute pressure at reference conditions, 101.3 kPa

Emission Rate

Determine the emission rate of total reduced sulphur compounds using Equation 5.3.

Equation 5.3

$$ER_{TRS} = 3600\ (C_{TRS})\ (Q_S)/10^6 \quad \text{Equation 5.3}$$

Where:

ER_{TRS} = emission rate of TRS, kg/h

C_{TRS} = concentration of TRS (as H_2S) at reference conditions, mg/m^3

Q_s = volumetric gas flow rate on dry basis at reference conditions, m^3/s

5.9 TEST RESULTS

The following information concerning the source test shall be included in the report.

Report Summary

(a) Date

(b) Permit number

(c) Name of plant

(d) Emission source tested

(e) Test objective

(f) Name plate (rated) capacity

(g) Process production rate during test

(h) Type of operation

(i) Process cycle tested

(j) Sampling location

(k) Test start/stop times

(l) Concentration of total reduced sulphur compounds

(m) Emission rate of TRS

(n) Stack gas flow rate

(o) Field data sheets

(p) TRS Analysis data sheet

Process Description

A brief description of the process, flow charts and documentation of process conditions during sampling shall be included in the report.

Test Results

This shall include:

(a) Pertinent operating data of the source tested

(b) Table listing stack test data

(c) Table listing stack gas composition, flow rate, molecular weight, TRS concentration and emission rate

Support Information

(a) All calibration data including procedures used and dates when calibrated

(b) Analytical procedures

(c) Equation used and sample calculations

METHOD 6:

Determination of Total Reduced Sulphur Compounds in Emissions from Stationary Sources using Thermal Oxidation

METHOD 6: DETERMINATION OF TOTAL REDUCED SULPHUR COMPOUNDS IN EMISSIONS FROM STATIONARY SOURCES USING THERMAL OXIDATION

6.1 PRINCIPLE

A gas sample is extracted from the stack gas and then passed through a citrate buffer to remove any SO_2 in the original sample. Sample total reduced sulphur (TRS) is oxidized to SO_2 in a quartz tube combustion furnace and collected in 3% v/v hydrogen peroxide where the sample is oxidized to sulphate. Analysis for sulphate is achieved by carrying out a barium perchlorate-thorin titration. The four compounds known collectively as total reduced sulphur (TRS) are hydrogen sulphide, methyl mercaptan, dimethyl sulphide and dimethyl disulphide.

6.2 APPLICABILITY

This method is applicable for determining emission of total reduced sulphur (TRS) compounds from stationary emission sources such as recovery furnaces, lime kilns and smelt dissolving tanks at Kraft Pulp Mills, etc.

6.3 INTERFERENCES

Incomplete oxidation of TRS compounds to SO_2 will result in a negative interference.

Incomplete removal of SO_2 from the original sample will result in a positive interference.

COS if present and if ozidized to SO_2 may yield a positive interference.

6.4 APPARATUS

Sampling Train

The sampling train for total reduced sulphur compounds shall be assembled as shown in Figure 6.1. The various components of the train are discussed below.

Probe

The sampling probe is stainless steel with a Pyrex glass liner. The probe shall be equipped with heating elements to maintain a minimum gas temperature of 120°C at the exit end. A suitably placed temperature sensor must be used for this purpose. Particulates are removed by a fine quartz or Pyrex wool plug at the probe inlet.

Impingers - Sulphur Dioxide Scrubber

Two modified Greenburg-Smith impingers connected in series, packed with glass wool to eliminate entrained mist and charged with 100 ml potassium citrate-citric acid buffer shall be used. Note that the buffer is prepared by dissolving 300 g potassium citrate and 41 g anhydrous citric acid in one litre of distilled water.

Combustion Tube

Quartz glass with an expanded combustion chamber of 22 to 25 mm and at least 30.5 cm long shall be used. The tube ends shall have an outside diameter of about 6 mm to accept Teflon tubing or Swagelok fittings.

Combustion Tube Furnace

A furnace with a combustion chamber of sufficient size to enclose the combustion tube shall be used.

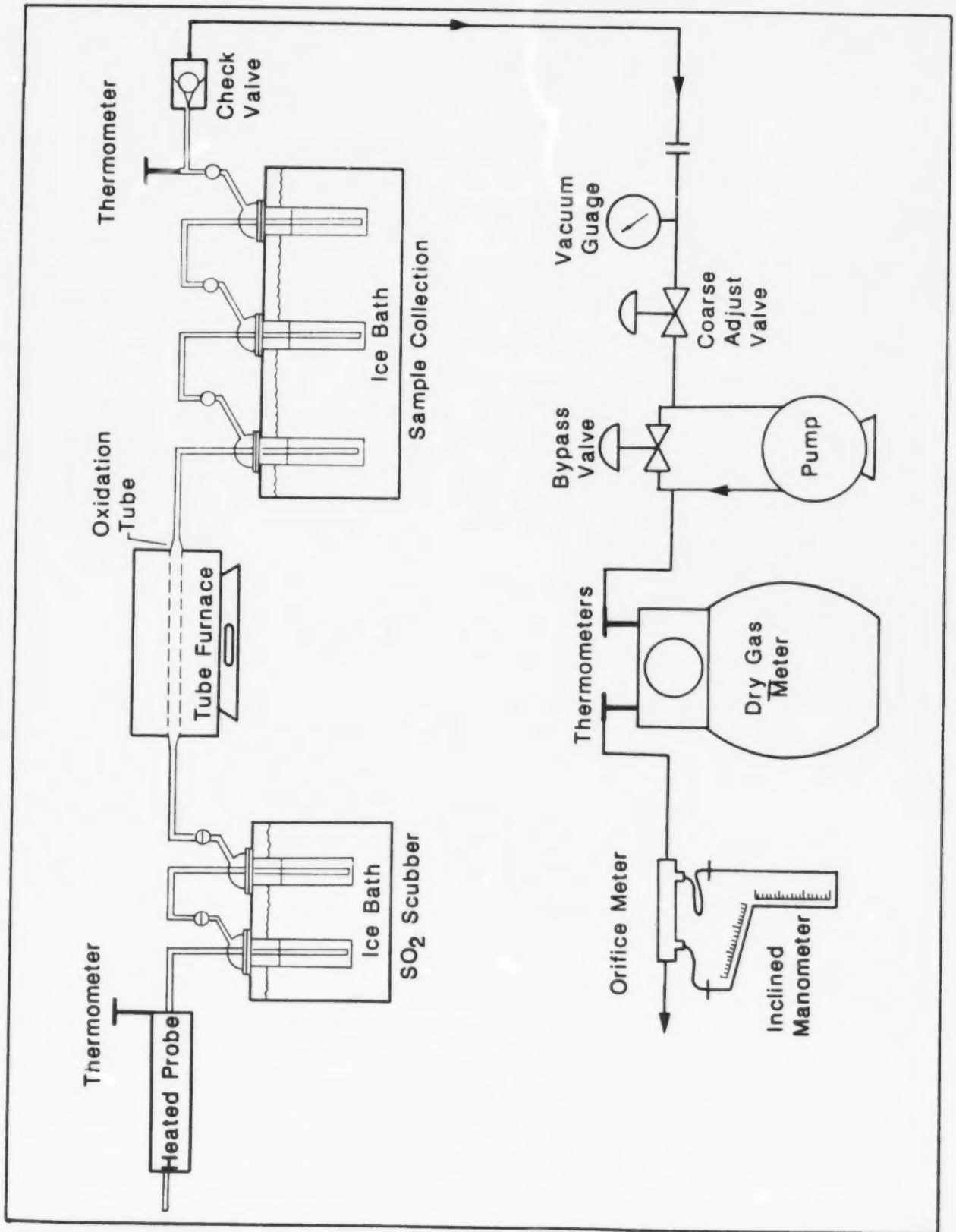

Figure 6.1 TRS Sampling Train

The furnace shall be equipped with a temperature regulator capable of maintaining the temperature at 815±15°C during sampling.

Impingers - Sample Collection

Three modified Greenburg-Smith impingers connected in series shall be used; the first two impingers shall contain 100 ml of 3% v/v H_2O_2 and the final impinger should contain approximately 400 g silica gel. A temperature sensor is placed at the outlet of the final impinger. The temperature of the exit gas leaving the final impinger should not exceed 25°C.

Metering System

A metering system consisting of a vacuum gauge, leak-free pump with coarse and final control valves, calibrated dry gas meter accurate to within ±1%, calibrated orifice meter (or rotameter) and temperature sensors capable of measuring to within ±3°C shall be used.

Pitot Tube

An S-type pitot tube/thermocouple assembly is necessary if the stack gas velocity varies with time and proportional sampling is required.

6.5 PROCEDURE

Pre-Sampling Preparations

The pitot tube (if used), dry gas meter, orifice meter (or rotameter) and temperature sensors must be

calibrated (refer to Apendix). Such calibration data must be available on request.

Select a suitable samplng location. The sampling point must be either at the centre of the stack or at least 50 cm from the nearest stack wall. For proportional sampling the sampling point must coincide with the reference point.

Assemble the sampling train (Figure 6.1) and test for any leakage. The leakage rate should not exceed 0.00057 m^3/minute (0.02 CFM).

Sampling Train Operation

Steady State Flow

For steady state sources a sample of stack gas shall be withdrawn at a constant sampling rate of approximately 5L/min.

Proportional Flow

If the stack gas velocity determinations show that the gas flow through the stack varies with time, sampling shall be done at a rate proportional to the square root of the (temperature corrected) stack gas velocity pressure. Attempt to maintain a mean sampling rate of 5L / min and adjust proportionally as the velocity pressure changes.

Valid Stack Survey

A minimum of three source tests, each one of 60-minute duration, shall be conducted in order to constitute a valid stack survey.

6.6 SAMPLE RECOVERY

Disconnect the probe, impingers and all inter-connecting glassware. Quantitatively, transfer the contents of the 2 sample collection impingers to a polyethylene container labelled "SO_2-H_2O_2". Also add the rinsings from the glassware connecting the 2 sample collection impingers. Seal the sample container for transportation to the laboratory.

Prior to re-initiating sampling, replenish the 2 sample collection impingers with 3% v/v H_2O_2, replenish the contents of the 2 impingers containing citrate buffer, clean the probe using the probe brush and rinse with distilled water, replace the probe filter, replace all inter-connecting glassware and re-assemble the sampling train.

6.7 SAMPLE ANALYSIS

Quantitatively transfer the contents of the "SO_2-H_2O_2" sample bottle to a 500 mL volumetric flask and dilute to volume with distilled water.

Add 10.0 mL sample and 40.0 mL 100% isopropanol to a 100 mL porcelain disk. Add 3-4 drops of thorin indicator and titrate to a pink end point using 0.01 N barium perchlorate.

Repeat the above procedure using 10.0 mL of 3% v/v H_2O_2 in place of 10.0 mL sample.

Analyze each sample 3 times and report a suitable average result.

6.8 CALCULATIONS

Gas Volume Sampled

Determine the volume of gas sampled at reference conditions of 293 K and 101.3 kPa using Equation 6.1.

$$V_{m(ref)} = \frac{2.89\ \upsilon\ P_{m(avg)} V_m}{T_{m(avg)}} \qquad \text{Eq. 6.1}$$

Where:

$V_{m(ref)}$ = volume of gas sampled at reference conditions, m^3

υ = dry gas meter correction factor, dimensionless

$P_{m(avg)}$ = average absolute pressure at the dry gas meter throughout the test, kPa

V_m = volume of gas sample recorded on dry gas meter, m^3

$(T_m)_{avg}$ = absolute temperature at dry gas meter, K

TRS Concentration

Calculate the concentration of total reduced sulphur (as H_2S) in the stack gas using Equation 6.2.

$$C_{TRS} = 17.02 \frac{N\ (V_t - V_{tb})\ V_{soln}}{(V_m)_{ref}\ V_a} \qquad \text{Eq. 6.2}$$

Where:

C_{TRS} = concentration of total reduced sulphur (as H_2S) as reference conditions, mg/m^3

V_t = volume of barium perchlorate used for sample, mL

V_{tb} = volume of barium perchlorate used for sample blank, mL

17.02 = (17.02 g H_2S/g-eq) x (L/1000 mL) x (1000 mg/g)

N = normality of barium perchorate titrant, g-eq/L

V_{soln} = total solution volume of sample, mL

V_a = volume of sample aliquot, mL

$(V_m)_{ref}$ = volume of gas sample through dry gas meter at reference conditions (293 K, 101.3 kPa), m^3

Volumetric Gas Flow Rate

Determine the volumetric gas flow rate, during sampling, using Equation 6.3.

$$Q_s = (U_s)avg \cdot A_s \cdot (1-B_{wo}) \frac{(T_{ref}) \cdot (P_s)}{(T_s)avg \cdot (P_{ref})} \quad \text{Eq. 6.3}$$

Where:

Q_s = volumetric gas flow rate on dry basis at reference conditions, m^3/s

$(U_s)avg$ = average stack gas velocity, m/s

A_s = cross-sectional area of stack m^2

B_{wo} = fraction by volume of water vapour in gas

T_{ref} = absolute temperature at reference condition, 293 K

$(T_s)avg$ = average absolute stack gas temperature, K

P_s = absolute stack gas pressure, kPa

P_{ref} = absolute pressure at reference conditions, 101.3 kPa

Emission Rate

Calculate the emission rate of total reduced sulphur (as H_2S) using Equation 6.4.

$$ER_{TRS} = 3600\ (C_{TRS})\ (Q_s)/10^6 \quad \text{Eq. 6.4}$$

Where:

C_{TRS} = concentration of total reduced sulphur (as H_2S) at reference conditions, mg/m^3

Q_s = volumetric gas flow rate on dry basis at reference conditions, m^3/s

ER_{TRS} = emission rate of total reduced sulphur (as H_2S), kg/h

ER_{TRS} = emission rate of total reduced sulphur (as H_2S), kg/h

6.9 TEST RESULTS

The following information concerning the source test shall be included in the report.

Report Summary

(a) Date
(b) Permit number
(c) Name of plant
(d) Emission source tested
(e) Test objective
(f) Name plate (rated) capacity)
(g) Process production rate during test
(h) Type of operation
(i) Process cycle tested
(j) Sampling location
(k) Test start/stop times
(l) Concentration of TRS
(m) Emission rate of TRS
(n) Stack gas flow rate
(o) Field data sheets

Process Description

A brief description of the process, flow charts and documentation of process conditions during sampling shall be included in the report.

Test Results

This shall include:

(a) Pertinent operating data of the source tested
(b) Table listing stack test data

(c) Table listing stack gas composition, flow rate, molecular weight, TRS concentration and emission rate

Support Information

(a) All calibration data including procedures used and dates when calibrated

(b) Analytical procedures

(d) Equations used and sample calculations

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BIBLIOGRAPHY

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APPENDIX A:

Calibration Procedure for S-Type Pitot Tube

METHOD A: CALIBRATION PROCEDURE FOR S-TYPE PITOT TUBE

A.1 PRINCIPLE

The S-type pitot tube and probe assembly are calibrated against a reference (standard) pitot tube with known coefficient. Calibration is conducted in a wind tunnel (or equivalent) which has both uniform and time invariant flow characteristics in the test section.

A.2 EQUIPMENT

Wind Tunnel

A wind tunnel with a flowing gas stream confined either in a circular or rectangular duct; the test section must have a constant cross-sectional area of at least 6000 cm^2 and the flow within the test section must be stable and parallel to the longitudinal axis of the duct. The gas stream is moved by a device capable of generating at least five different stream velocities; these velocities should reasonably cover the range of velocities anticipated in the field. Equipment with alternate specifications may be acceptable but must have prior written approval from the Ministry.

Reference Pitot Tube

A standard pitot tube of known coefficient.

Differential Pressure Gauges

Inclined manometer (or equivalent device) readable to nearest 0.001 kPa (0.13 mm H_2O).

A.3 PROCEDURE

Position the S-type pitot tube (probe assembly) at the centreline of flow and 4-5 equivalent diameters downstream of the reference pitot tube. Seal the pitot tube entry ports. Attach manometers to each of the pitot tubes. Inspect and leak check all pitot lines. Level and zero the manometers.

Turn on the fan and allow the flow to stabilize at the appropriate velocity. Measure and record the velocity pressures from the reference pitot, ΔP_R and the S-type pitot ΔP_S, at 5-6 successive velocities at approximately equally spaced intervals over the required range. Align the pitot so that its tip is pointed directly into the flow. Record the measurements on the data sheet illustrated in Table A.1.

A.4 CALCULATIONS

The S-type pitot coefficient C_p is calculated using equation A.1.

$$C_p = C_R\left(\frac{\Delta P_R}{\Delta P_S}\right)^{1/2} \qquad \text{Eq. A.1}$$

Where

C_p = coefficient of S-type pitot tube

C_R = coefficient of reference pitot tube

TABLE A.1

CALIBRATION CERTIFICATE S-TYPE PITOT TUBE

Date: _____

Pitot I.D.: _____

Nozzle I.D.: _____

Approx. Wind Vel.	Ref. Pitot Vel. Press.		S-Type Pitot Vel. Press.	
	ΔP_R	$C_R\sqrt{\Delta P_R}$	ΔP_S	$\sqrt{\Delta P_S}$

CALIBRATION EQUATION

$C_R\sqrt{\Delta P}_R = C_p\sqrt{\Delta P}_S$ $\qquad C_R =$ _____

$C_p =$ _____

ATTACHMENTS

Calibration Curve _____

ΔP_R = velocity pressure measured by reference pitot
ΔP_S = velocity pressure measured by S-type pitot

Plot graph of $(\Delta P_S)^{1/2}$ versus $(\Delta P_R)^{1/2}$.
Determine the slope and calculate C_p.

APPENDIX B:

Calibration Procedure for Dry Gas Meter and Orifice Meter

METHOD B: CALIBRATION PROCEDURE FOR DRY GAS METER AND ORIFICE METER

B.1 PRINCIPLE

The dry test and orifice meters of the particulate sampling train are calibrated using a wet test meter.

B.2 EQUIPMENT

Wet Test Meter

A wet test meter or equivalent capable of measuring 0.028 m^3 per revolution with ± 1% accuracy.

B.3 PROCEDURE

Dry Gas Meter

Connect the wet test meter as shown in Figure B.1. Ensure that a drying tube is installed between the wet test meter and pump. Start the pump and allow the system to come to equilibrium. Adjust the flow through the system to approximately 0.007 - 0.014 m^3/min. After the warm-up period, run tests and record the required parameters on the data sheet illustrated in Table B.1.

Orifice Meter

Disconnect the wet test meter. Ensure that a drying tube is installed before the pump. Start the pump and allow the system to come to equilibrium. After the warm-up period, run tests and record the required parameters on the data sheet illustrated in Table B.2.

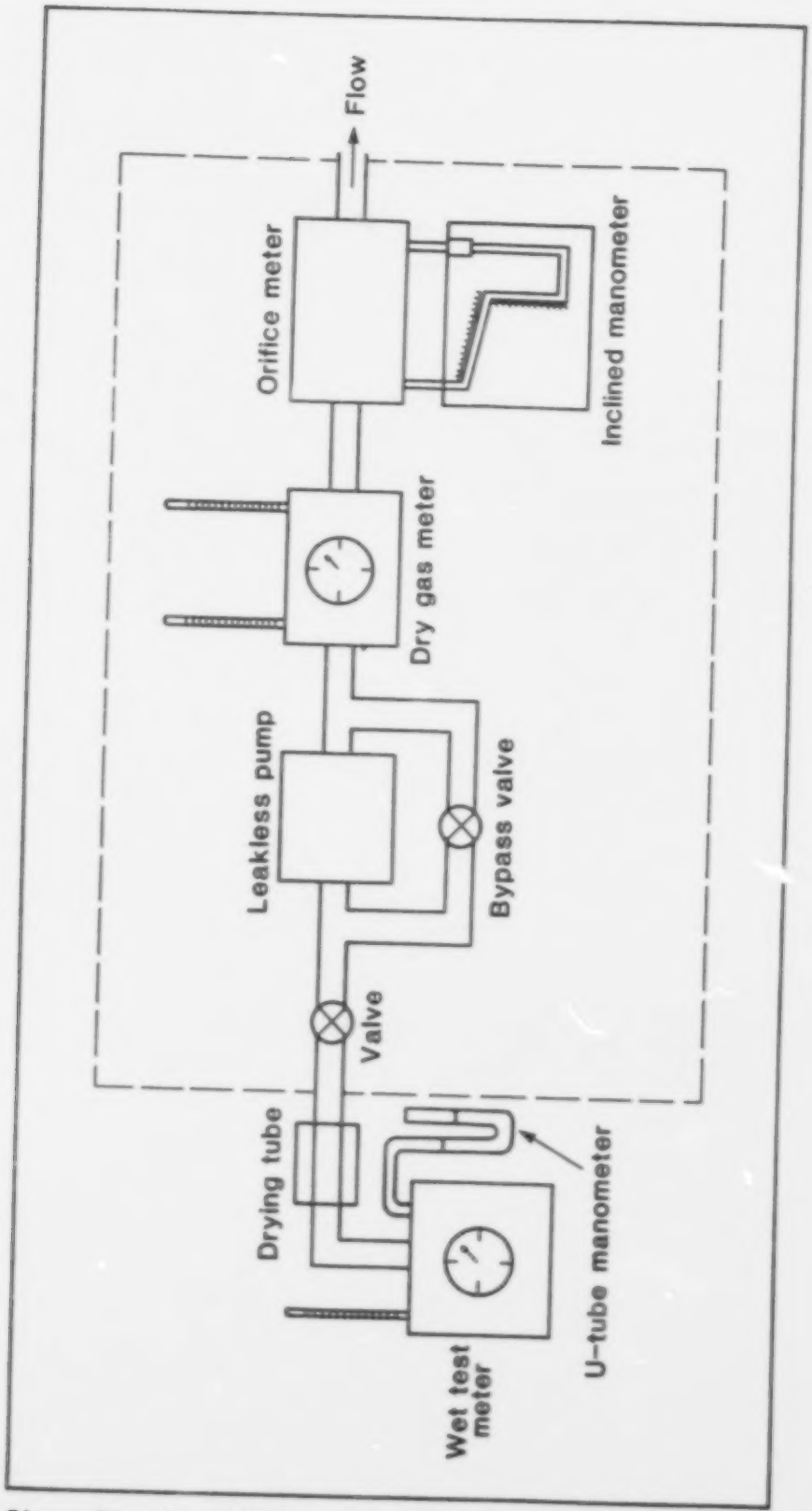

Figure B1 Assembly for Calibration of Dry Gas and Orifice Meters

TABLE B.1

DRY GAS METER CALIBRATION CERTIFICATE

Date: _____

Console I.D.: _____

PARAMETER SUMMARY

	Run No. 1	Run No. 2	Run No. 3
T_a = ambient (wet test meter) temp. °C			
ΔP = press. diff. at wet test meter, kPa			
P_b = atmospheric pressure, kPa			
P_v = Vapour press. water at temp. T_a, kPa			
ΔH = press. diff. at orifice, kPa			
T_i = dry test inlet temp. °C			
T_o = dry test outlet temp. °C			
R_i = initial dry test vol. m^3			
R_f = final dry test vol. m^3			
V_i = initial wet test vol. m^3			
V_f = final wet test vol. m^3			
$P_W = P_b + \Delta P$, kPa			
$P_D = P_b + \Delta H$, kPa			
$T_W = T_a + 273$, K			
$T_D = [(T_i + T_o)/2] + 273$, K			
$B_w = P_v/P_b$			
CALCULATED v VALUE			

CALIBRATION EQUATION $$v = \frac{V_f - V_i}{R_f - R_i} [(P_w/P_D)(T_D/T_w)] \cdot (1 - B_w)$$

v(MEAN) = _____

AUTHORIZATION _____

Calibration Section

Orifice Meter

Flow through the orifice meter may be determined using Equation B.2.

$$Q_m = K_o \left(\frac{T_m}{P_m} \cdot \frac{\Delta H}{M_d} \right)^{1/2} \qquad \text{Eq. B.2}$$

Where

K_o = proportionality constant

$$= \frac{m^3}{min} \left(\frac{kg}{K\ kmol} \right)^{1/2}$$

T_o = dry test meter outlet temperature °C

$T_m = T_o + 273$, K

P_b = absolute barometric pressure, kPa

ΔH = pressure drop across the orifice meter, kPa

$P_m = P_b + \Delta H$, kPa

M_d = molecular weight of dry air, 28.95 $\frac{kg}{kmol}$

Q_m = flow through the orifice meters, m^3/min

R_i = initial dry gas volume, m^3

R_f = final dry gas volume, m^3

The proportionality constant K_o is specific for the orifice meter being calibrated and is determined by varying the flow rate over the working range of the orifice meter and plotting Q_m versus $(T_m/P_m \cdot \Delta H/M_d)^{1/2}$.

TABLE B.2

ORIFICE METER CALIBRATION CERTIFICATE

Date: _____
Console I.D.: _____

PARAMETER SUMMARY

M_d = Mol. wet dry air, $\frac{kg}{kmol}$	28.95					
P_b = atmospheric pressure, kPa						
ν = dry gas meter calib. const.						
ΔH = orifice press. diff, kPa						
R_i = initial dry gas vol, m^3						
R_f = final dry gas vol, m^3						
Δt = meas. interval (min)						
$Q_m = \nu (R_f - R_i)/\Delta t$, m^3/min						
T_o = outlet dry gas temp., °C						
$T_m = T_o + 273$, K						
$P_m = P_b + \Delta H$, kPa						
$(T_m/P_m \cdot \Delta H/M_d)^{1/2}$						

CALIBRATION EQUATION

$Q_m = K_o (T_m/P_m \cdot \Delta H/M_d)^{1/2}$

K_o = _____

ATTACHMENTS

Calibration Curve _____

AUTHORIZATION

_____
Calibration Section

B.4 CALCULATIONS

Dry Gas Meter

Calculate v, the ratio of the wet test meter to dry test meter volume using equation B.1.

$$v = \frac{V_f - V_i}{R_f - R_i} \; (P_W/P_D)(T_D/T_W) \cdot (1 - B_{wo}) \qquad \text{Eq. B.1}$$

Where

v = ratio of wet test meter volume to dry test meter volume, dimensionless

P_b = absolute barometric pressure, kPa

ΔP = pressure drop across wet test meter kPa

$P_W = P_b + \Delta P$, kPa

V_f = final wet test volume m^3

V_i = initial wet test volume, m^3

R_f = final dry test volume, m^3

R_i = initial dry test volume, m^3

ΔH = pressure drop across the orifice meter, kPa

$P_D = P_b + \Delta H$, kPa

B_{wo} = fraction by volume of water vapour passing through the wet test meter calculated from partial pressure data = P_v/P_b

T_i = dry test meter inlet temperature, °C

T_o = dry test meter outlet temperature, °C

$T_D = [(T_i + T_o)/2] + 273$, K

T_a = ambient (wet test meter) temperature, °C

$T_w = T_a + 273$, K

P_v = absolute vapour pressure of water at temperature T_a, kPa

P_b = absolute barometric pressure, kPa

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